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X - RAY TUBES

Alfredo Castellano

Universita di Lecce
Lecce

BUILDING STRADA COSTIERA, 11 TEL 22401 TELEFAX 224163 TELEX 460392 ADRIATICO GUEST HOUSE VIA GRIGNANO, 9 TEL 224241 TELEFAX 224531 TELEX 46044

X-Ray Tubes

Alfredo Castellano

X RAY TUBES

X-ray tubes are widely employed in diagnostic radiology and in radiotherapy. However their use is not only limited to these fields.Other applications like not destructive controls, crystallography, X-ray fluorescence ask for the use of these devices.

X-rays are produced when a material is bombarded with a beam of charged particles with high speed.

Substantially an X-ray tube (see Fig.1)consists of a glass envelope with inside an high vacuum (10 mmHg), of a cathode made with a tungsten filament and an anode where electrons accelerated through an applied potential difference are suddenly stopped.

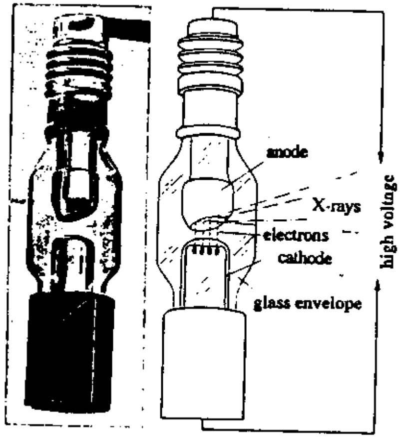


Fig1.Photograph and diagram of an X-ray tube.

Construction tecnique

Tubes consist of metallic electrodes and glass envelope.The metallic electrodes are first machined then they are cleaned with chemical solvents and ultrasonic methods.Finally they are deposited in high vacuum chambers at high temperature in preoutgassing owen.To these treatments it follows the glass-to-metal seal of the electrodes and the evacuating of the vessel.During the evacuating the temperature of the glass envelope is raised to 400°C and the temperature of the electrodes is raised to 700°C,using high frequency generators,to eliminate residual gases.After some hours the tube is removed from the vacuum pump and vacuum is increased with the atctivation of getters inside the tube wich absorb residual gases which have not been eliminated by vaccuum pump and other eventual gases that may be produced during the use of the tube.

Fundamentals of X-ray tubes

In common type of radiological tube the electrons are produced with termoelectronic effect in the filament in which runs an electrical current.Electronic emission from the surface unit of the filament is (Richardson):

$$J=CT^{2}\exp(-b/KT) \quad \frac{A}{m^{2}}$$

with C = constant depending from the surface and form the material of the filament A/cm T

b = work function of the emitter in eV

K = Boltzmann constant 8.62 10 eV/°K

T = absolute temperature in °K

It is easy to see that J raises suddenly with T.In Fig.2 are shown various type of filament for X-ray tubes.

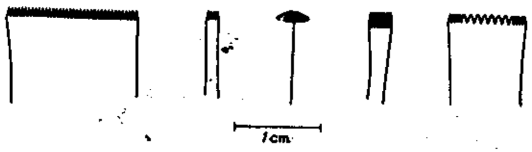


Fig.2.Filaments for X-ray tubes.

The anode consists of a tungsten target imbedded in a massive piece of copper.Between the cathode and the anode is applied ,as already told, a potential difference that accelerates the electrons which,after the collision with the anode, lose their energies producing X-rays.The great part of energy lost is converted into heating.Only 1% of the total energy is trasformed in X radiations.

The yield is given by the ratio between energy of the X radiation on the energy of the chatodic beam

$$\eta = \text{energy of X radiation / energy of cathode beam}$$

the yield is independent from the current I circulating in the tube, but it is proportional to the accelerating voltage and the atomic number Z of the anode.

$$\eta = \eta_0 Z V \% \qquad \text{with } \eta_0 = 10^{-9} \quad \text{and V in Volt}$$

Cooling

All the energy of the electronic stream is absorbed by the anode and is concentrated on a small surface (focal spot).The target surface raises its temperature and may reach its melting point if adequate systems of cooling are not present.In Fig.3 it is shown a deformed anode surface.The deformation strongly reduces the yield emission of X-ray.

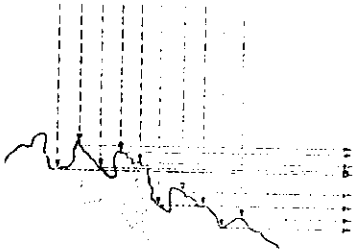


Fig.3.A deformed anode.

To reduce the surplus of heating, the copper anode, on wich is imbedded the tungsten target, is made hollow,Fig.4,to permit the circulation of cooling liquids which consist of water or oil.

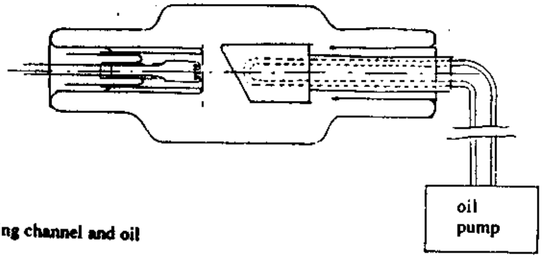


Fig.4.Cooling channel and oil pump.

The tubes that operate with large current are generally of the type called "rotating anode".This anode consists of a tungsten disc and the focal spot is located towards the edge of the same disc which is

rotating(see Fig.5).The heat produced is therefore distributed on a wide area whereas the geometry of the effective focal spot remains constant.The reduction of the temperature is proportional to the circumference described by the focal spot and to the rotation speeds.

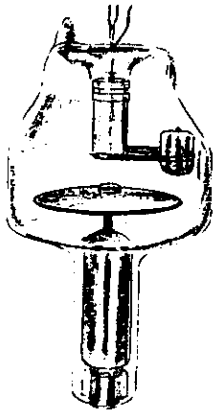


Fig.5.Rotating anode tube.

The manufacturers generally supply in the user's manuals the elements that permit the users to calculate the maximum loading of the tube.

Focal spot dimensions

One of the requirements more important in diagnostic radiology is relative to the focal spot dimensions.

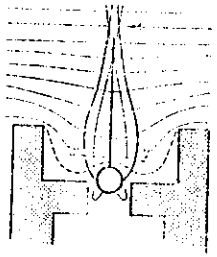


Fig.6.A focusing cathode.

To obtain images with a good sharpness radiographic images must be produced "lighting" the examined object with a source whose dimensions are very small,in general smaller than the details one wish to resolve.This is obtained making the filament very small and shaping the cathode in such a way that the electrons are focalized on the anode (see Fig.6).In Fig.7 it is shown an electron beam with dimension 2x7 mm striking the anode with a slope of 18°, such as ,seen from the bottom, the beam appears coming from a struck area of 2x2 mm.The source appears small and the power is distributed on a relative large surface.

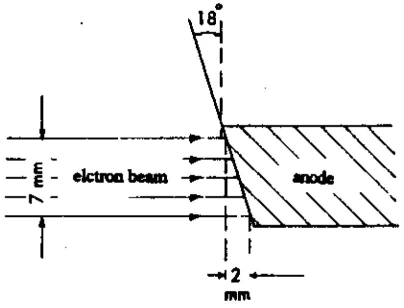


Fig.7.Diagram illustrating the line focus tube.

In the therapy tubes, since it is not important to have very small sources, the slopes of the anodes are 30° - 40° and the diameters of the appearing sources are about 5 mm large.In these tubes the powers are about 1/10 of the powers of the diagnostic tubes, but their working times are much longer.Cooling is obtained through forced circulation of cooling liquids.

Electrical charateristics and X-ray output

The current I inside the tube depends on the filament temperature therefore from the current i circulating in the filament.For a given value of the current i, I also depends on the voltage V applied between anode and cathode.In Fig.8 it is shown I as a function of V for two different filament currents.

From the figure it is possible to see that:

a)at low accelerating voltages V the current I inside the tube is governed by the effect of "space charge" ,so, increasing the voltage it is possible to increase the current and consequently the X-ray emission;

b)at high voltages > 30 - 40 kV a saturation region is reached,then increasing of the voltage does not increase the current I and the X-ray emission.The current I raises only by increasing of the filament currents i.

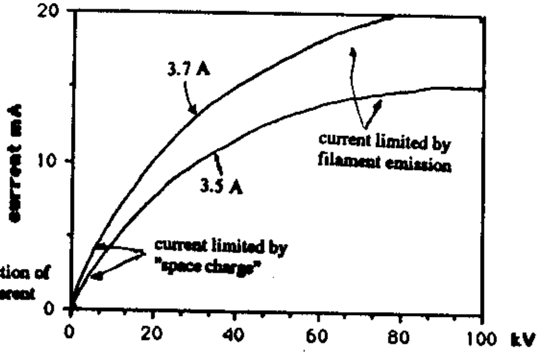


Fig.8.Current as a function of kilovoltage for two different filament currents.

Many tubes have a very limited space charge region and they works mainly in region of saturation.

In Fig.9 it is shown a typical electrical drawing of an X-ray generator.Other high voltage circuits are shown in Fig.10

Outputs at constant potential measured with a ionization chamber of an X ray generator with tungsten target and various filtrations are shown in Fig.11-12.

At constant potential the outputs are proportional to the current I inside tube.See Fig.13

In appendix is described a ionization chamber vented to the air designed to control the output of an X-ray tube.The same flat ionization chamber, placed between the diaphragm of the X-ray tube and the patient, has been used to measure the dose absorbed by patients during medical X-ray examinations.

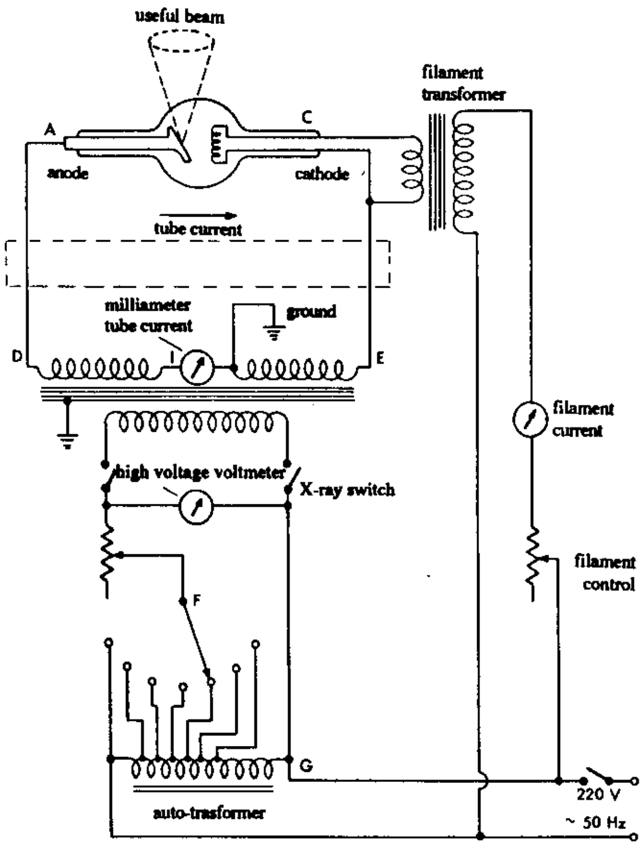


Fig.9.Electrical drawing of a self rectified X-ray generator.

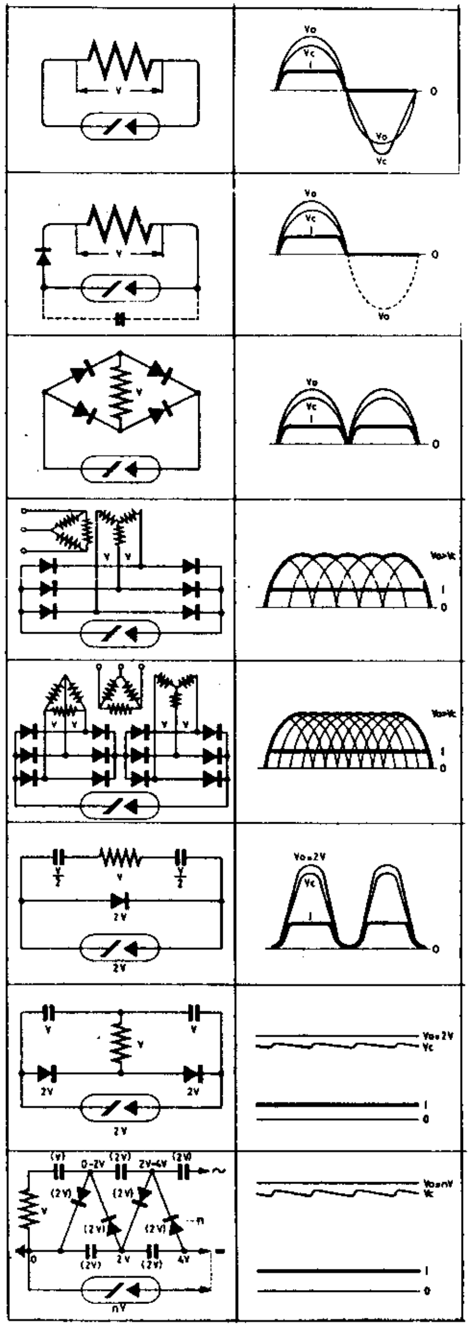


Fig.10.High voltage drawings.

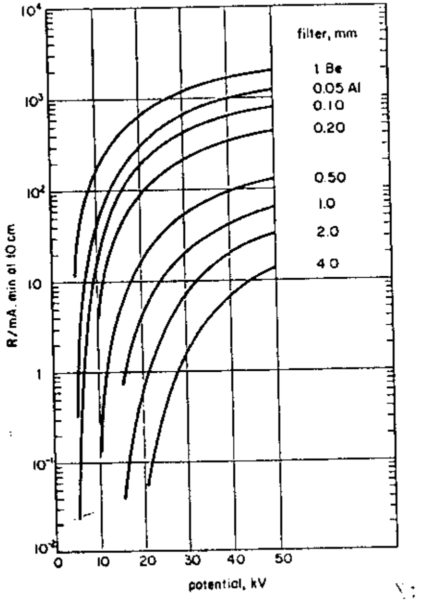


Fig.11.Output of constant potential x-ray generator at 10cm target distance for various beam filtrations and anode tungsten target.The tube window thickness is 1 mm beryllium.

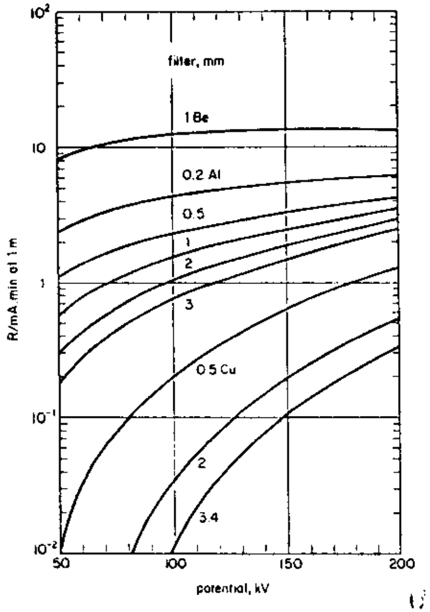


Fig.12.Output of constant potential x-ray generator at 1m target distance for various beam filtrations and anode tungsten target.The tube window thickness is 1mm beryllium.

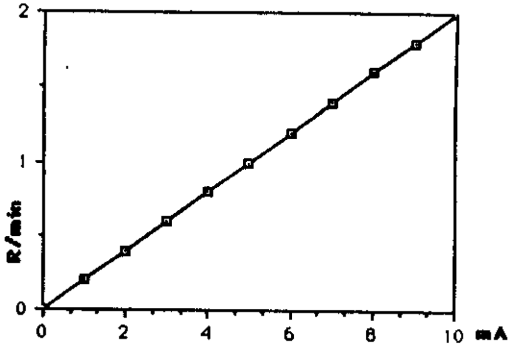


Fig.13.Plot of the exposure rate as a function af the tube current with the kilovoltage held constant - 100 kV. Filtration 0.5 mmCu.

Half Value Layer - HVL

Two quantities commonly used to charaterize an X-ray beam are the half value layer (HVL) and the homogeneity factor.The half value layer is the thickness of absorbing material required to reduce to one half the intensity of a beam.

Requirements necessary to measure the HVL are a well collimated beam and a small area detector in order to eliminate the contributions of the diffused radiations(good geometry).

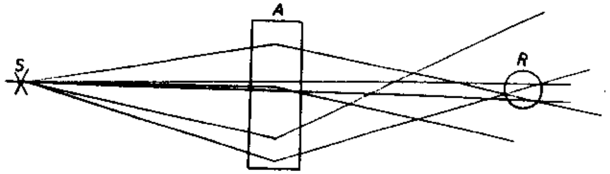
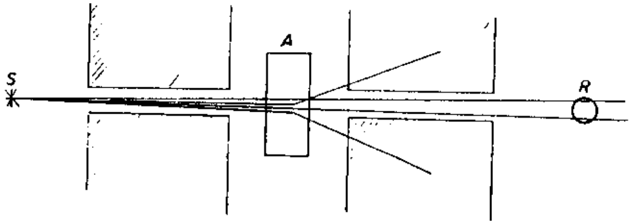


Fig.14."bad geometry" and "good geometry" configurations.



In Fig.14 the configurations relative to the "good geometry"and "bad geometry" are shown.A possible configuration for HVL determinations shown in Fig.15.

Plotting the trasmissivity through copper filters in "good geometry" of an X-ray beam on semi-log scale is possible to obtain plot like in Fig.16 for a 200 kV tube.One should remarke that the slope of the curve changes with the thickness of the absorber.The variations are due to the fact that the polychromatic beam may be though like the sum of monoenergetic beams with different intensities.The slope of the curve vanishes with the raising of the filtration because the softer components are almost completely absorbed and the radiation is more monochromatic.

A radiation beam is called homogeneous when the HVL is constant for any value of the absorber thickness.The ratio

d = HVL n-th /HVL (n-1)th

is the homogeneity degree.

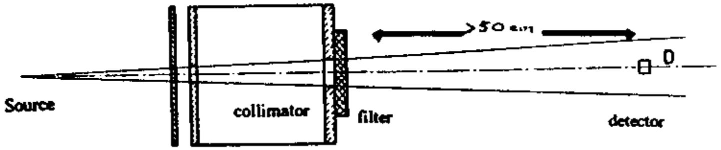
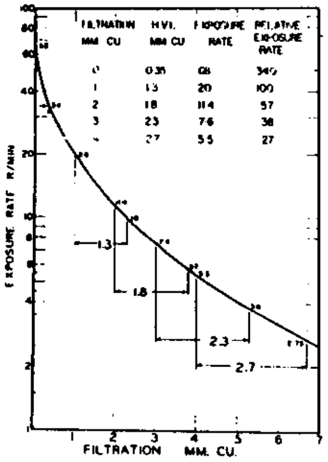


Fig.15.Arrangement for HVL measurement

Fig.16.Absorbtion curve for a 200 kV x-ray tube.

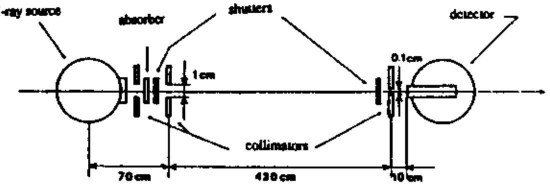


X-ray spectrometry

As already shown the parameters normally used for the characterization of X-ray beams are: the high voltage, the half value layer and the homogeneity factor.The measure of the x-ray spectra gives great informations for the optimazation of radiological imaging.The measurement of x-ray spectra may be carried out using NaI or Ge(Li) detectors.Ge(Li) detectors,due to its high resolution is preferable because makes the corrections spectra negligible.

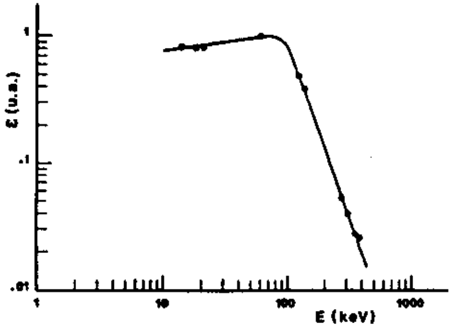
In Fig.17 is shown the experimental set-up for x-ray spectra measurements with a Ge(Li) detector.

Fig.17.Experimental set-up for X-ray spectra measurements



The counting system must be calibrated because the efficency of the detector is not uniformly over the whole energy spectrum.In Fig.18 is shown the efficency curve vs x-ray energy of the used Ge(Li) detector.

Fig.18.Efficency curve vs x-ray energy for a Ge(Li) detector



From the figure appears obvious that some corrections must be applied to the recorded pulse spectrum.The spectra shown in Fig.19 has been modified with a "stripping" mathematical procedure that takes on account the efficency curve already shown.

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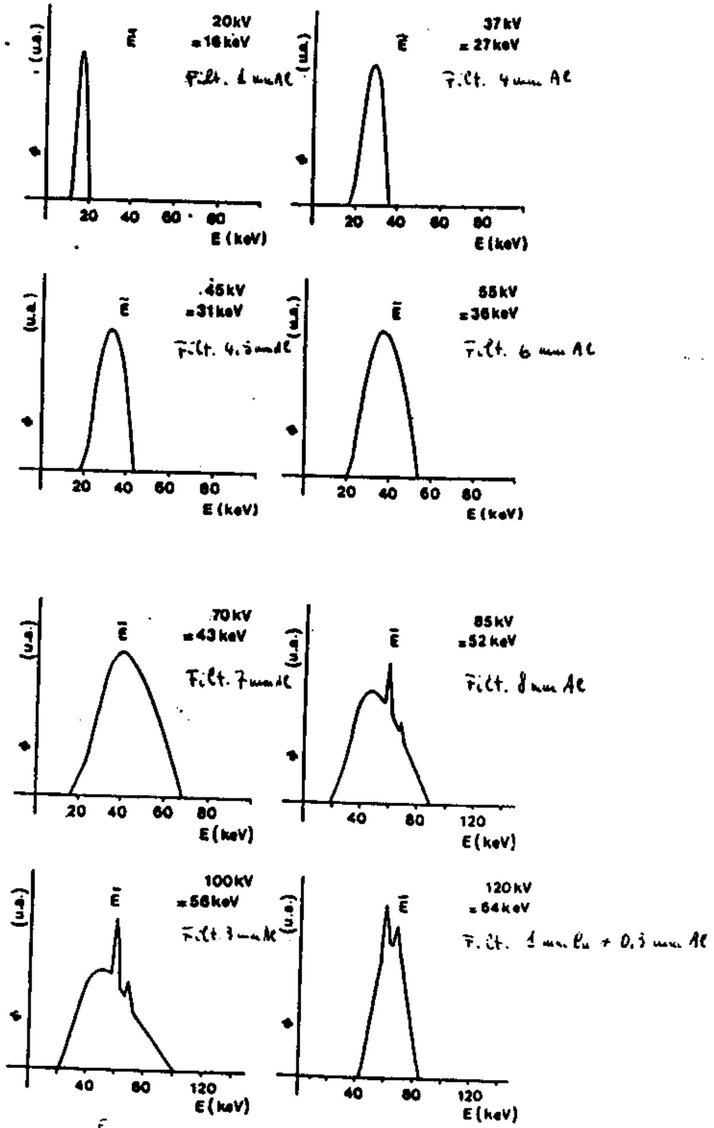

$$\bar{E} = \frac{\int_0^{E_{max}} \phi(E)\, E \, dE}{\int_0^{E_{max}} \phi(E)\, dE}$$

Fig.19.X-ray spectra at various energy and filtrations.

APPENDIX

A DUAL IONIZATION CHAMBER AND ASSOCIATED ELECTRONICS

Castellano Alfredo, Staderini Enrico M.

INTRODUCTION

Ionization chambers are widely used form dosemetric purposes. Various shapes and configurations of such type of devices have been proposed to solve particular problems connected with the industry and research activities, Large volume cylindrical ionization chambers are commonly used in radioprotection while free air ionization chamber (1) are used as primary standard of exposure in metrology. The use of this kind of chambers has moreover gained popularity in controlling and recording radiation exposure in industrial gammagraphy or in measuring patient dose in X-ray diagnostics and radiotherapy (2).

The control of gamma or X-ray beams has brought the authors of the present paper to realize a dual ionization chamber made coupling to plane parallel ionization chambers as in fig. 1 that can be installed on the diaphragm of the X-ray tube or gamma source to measure the product of exposure and exposed area (Ckg^{-1}m^{2}). Two ionization chambers have been already used in a configuration similar to ours, the Kemp comparator circuit (3), or to measure peak beam energy by different exposure of each chamber to the same beam. On the contrary in the proposed instrument both chambers have to be equally irradiated and the outputs are substracted each other to give a high noise reduction.

PRINCIPLE OF OPERATION

The ionization chamber is usually a critical operation instrument due to mains interference, leakage current and time instability. The sensitivity of the device is proportional to the chamber's volume but this cannot be increased very much if the problems cited above have to be avoided.

In an attempt to overcome the difficulties generally associated with ionization chambers manufacturifng and use, a new device has been designed

using original strategies in the chambner and associated electronics yo simplify construction of the chamber and or to make possible the realization of large chamber for special puproses.

The system makes use of a dual ionization chamber assembly actually composed of two equal chambers (which have to be equally irradiated) connected in a dual high voltage (+- 180V) power supply. The currents flowing from the collecting electrodes of the chambers are differentially amplified with an instrumentation amplifier whose voltage output is fed into low pass and notch filters.

Due to differential amplification, ionization and leakage currents from the two chambers are summed because they are always opposite while same polarity correlated noise (tipically mains interference) is efficiently removed. Then a low pass filter cancels uncorrelated noise and a mains notch furthermore reduces interference.

The voltage so obtained and filtered is contaminated by leakage component which is then removed by a sample and hold device (S&H). Since the current from non-irradiated chambers is only composed of the leakage part, the S&H latches, in this case, the value of the leakage signal to be subsequently subtracted from the signal coming from the irradiated chambers.

The pure ionization signal thus obtained is amplified and frequency converted so as to be simply integrated by digital counting (4) or recorded on magnetic tape.

MATERIALS AND METHODS

The dual chamber used in the prototype (5) was manufactured using mylar 1 mm thick foil coated with aluminium. Each chamber consists of 40 cc air vented chamber. Spacing between the conductive layers is 2 mm and the high voltage supply is 180 V. The chambers so designed are practically independent from the wavelenght of the incident radiation in the range from 2 mm Al HVL to 7 mm Al HVL.

The wiring diagram of the ionization chamber electronics is shown in fig. 2.

The instrumentation amplifier has a differential gain of 1.9 and a common mode rejection ratio (CMRR) trimmable to 100 dB at best with an input impedance of the order of teraohms. The low pass filter ia a 1200 Hz corner frequency second order unity gain device. The notch filter has unity gain with a 20 dB attenuation at local mains frequency (50 Hz). S&H is a standard commercial type featuring very low drop rate. The signal out of the S&H follows the input when the voltage of pin 7 is logical low; as the pin 7 voltage goes high the last input voltage is latched at the input. The differential amplifier subtracts the S&H output from the signal with unity gain and the subsequent amplification has a factor of 40. The voltage to frequency converter used has a transfer function of 5 Hz/mV with wide dynamics and good stability.

DISCUSSION

The proposed instrument appears to overcome some drawbacks of actual ionization chamber design; in particular the active mains noise rejection allows the construction of chambers of various volumes and shapes with less stringent constraints on shielding.

The leakage current subtraction is an even more interesting feature; it allows one to amplify the signal (having a zero leakage bias) and increases chamber sensitivity. A drawback of the leakage subtraction circuit proposed lies in the drop rate of analogical S&H used. This accounts for the necessity of periodic recalibration (every one or two minutes) of the instrument (resampling the leakage without radiation) which strongly limits the measure time. A solution to this problem would be the use of a digital S&H composed of an analog to digital converter, a digital register memory and a digital to analog converter. In this way the drop rate would go to zero but proper considerations on resolution and accuracy of conversion have to be made. At least 12 bit resolution conversion seems adequate for certain uses but in general an ionization chamber can span a wide radiation dynamic range before showing saturation. If an analog to digital conversion is to be made, then subtraction may also be performed digitally and the use of the computer is straightforward.

Nevertheless actual performances of the instrument are adequate for measuring X-ray fields for diagnostic purposes over a short integration time.

The voltage to frequency converter is a simple way to obtain a signal easy to integrate and even to record on tape. The usefulness of such device is particularly evident when very low values are to be integrated.

A modified prototype with minor amplification in the last stage was used as a skin-exposure exposed-area product meter and was found useful to minimize the dose resulting from X-ray examinations without reduction of medical benefit as recommended by various international organism devoted to patient radioprotection.

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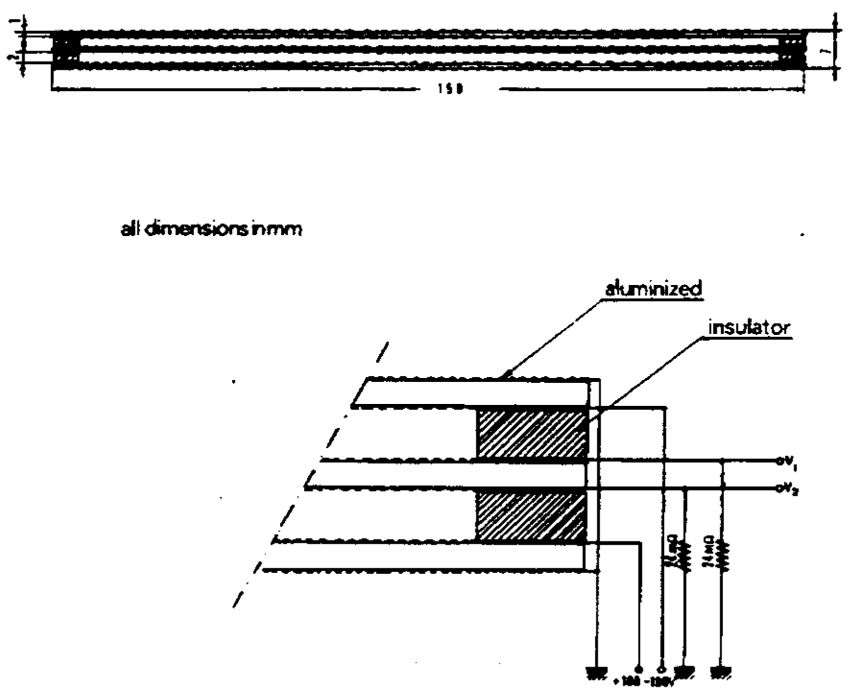

Fig. 1: Some details of the dual chamber

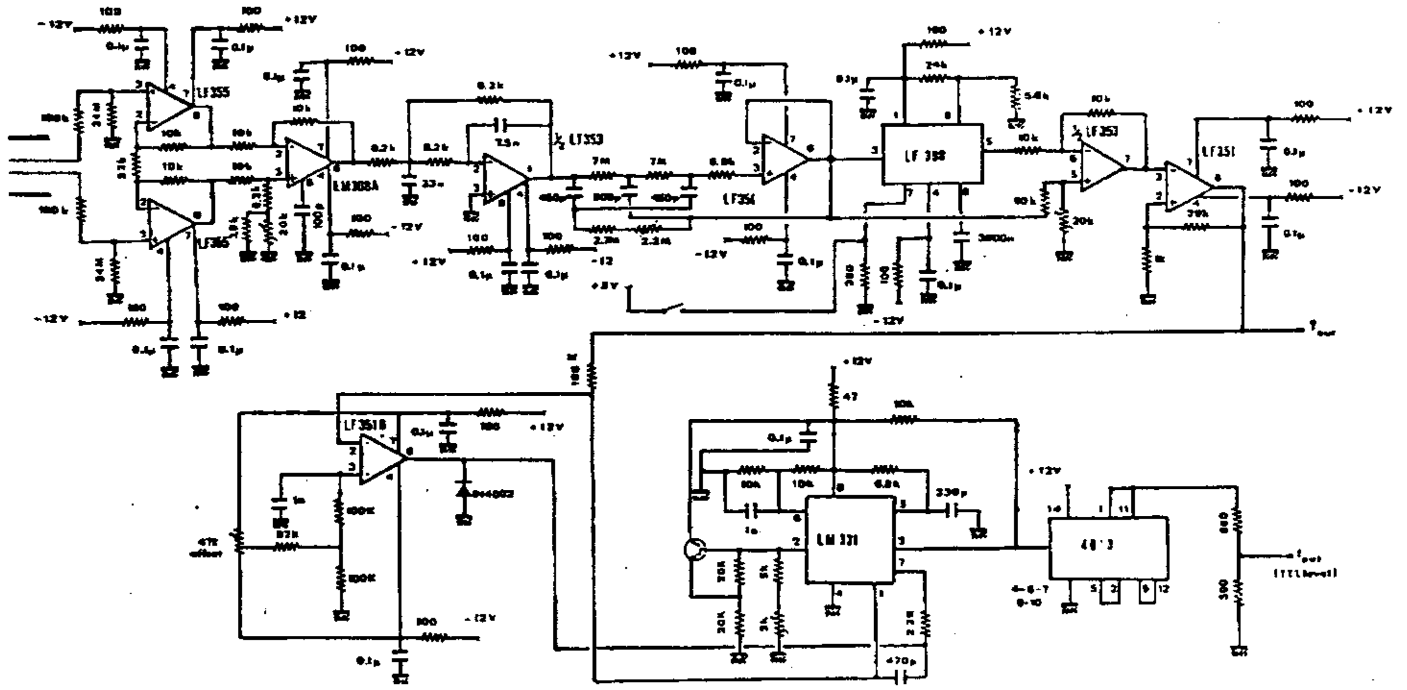

Fig. 2: Wiring diagram of the ionization chamber electronics